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1 (presently amended). A method for providing for transport of thermal energy from an object, the method comprising:

providing an array of carbon nanotubes or carbon nanofibers, referred to herein as "CNTs," ~~on~~ embedded in a selected surface of a selected substrate having high thermal conductivity, where at least first and second CNTs in the array are oriented substantially perpendicular to the selected surface;

after provision of the at least first and second CNTs in the array, filling at least a portion of an interstitial space between at least two adjacent CNTs in the array with a selected filler material that has high thermal conductivity so that the filler material makes contact with the selected substrate surface at a first end of each of the at least first and second CNTs and a second end of each of the at least first and second CNTs is exposed and is not fully covered by the filler material; and

causing the exposed second ends of the at least ~~one of the~~ first and second CNTs to make contact with a surface of an object for which transport of thermal energy is to be provided so that at least one of the exposed second ends of the CNTs bends or buckles, whereby thermal energy is removed from the object through the at least first and second CNTs and a portion of the removed thermal energy is distributed within the filler material.

2 (canceled).

3 (original). The method of claim 1, further comprising selecting said filler material to include at least one of Cu, Ag, Au, Pt, Pd and a metal-doped silicide.

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4 (original). The method of claim 1, further comprising providing a layer of a selected catalyst, including at least one of Ni, Fe, Co, Pt and Al, for growth of said array of said CNTs, on said selected surface of said catalyst.

5 (original). The method of claim 1, further comprising filling said portion of said interstitial space with said filler material by a process comprising at least one of chemical vapor deposition, physical vapor deposition, plasma deposition, ion sputtering, electrochemical deposition and casting from a liquid phase.

6 (original). The method of claim 1, further comprising providing said exposed second ends of said at least first and second CNTs by a process comprising at least one of mechanical polishing, chemical-mechanical polishing, wet chemical etching, electrochemical etching and dry plasma etching.

7 (presently amended). Apparatus for providing for transport of thermal energy from an object, the apparatus comprising:

an array of carbon nanotubes or carbon nanofibers, referred to herein as "CNTs," ~~as~~ embedded in a selected surface of a selected substrate having high thermal conductivity, where at least first and second CNTs in the array are oriented substantially perpendicular to the selected surface;

a high thermal conductivity material that fills at least a portion of an interstitial space between at least two adjacent CNTs in the array so that the filler material makes contact with the selected substrate surface at a first end of each of the at least first and second CNTs and a second end of each of the at least first and second CNTs is exposed and is not fully covered by the filler material; and

wherein the exposed second ends of the at least ~~one of the~~ first and second CNTs make contact with a surface of an object for which transport of thermal

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energy is to be provided so that at least one of the exposed second ends of the CNTs bends or buckles, whereby thermal energy is removed from the object through the at least first and second CNTs and a portion of the removed thermal energy is distributed within the filler material.

8 (canceled).

9 (original). The apparatus of claim 7, wherein said filler material includes at least one of Cu, Ag, Au, Pt, Pd and a metal-doped silicide.

10 (original). The apparatus of claim 7, further comprising a layer of a selected catalyst, including at least one of Ni, Fe, Co, Pt and Al, deposited on said selected substrate surface for growth of said array of said CNTs, on said selected substrate.

11 (original). The apparatus of claim 7, wherein said portion of said interstitial space is filled with said filler material by a process comprising at least one of chemical vapor deposition, physical vapor deposition, plasma deposition, ion sputtering, electrochemical deposition and casting from a liquid phase.

12 (original). The apparatus of claim 7, wherein said exposed second ends of said at least first and second CNTs are provided by a process comprising at least one of mechanical polishing, chemical-mechanical polishing, wet chemical etching, electrochemical etching and dry plasma etching.

13 (previously presented). The method of claim 1, further comprising providing said exposed ends of said first and second CNTs in said array with an

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exposed first length and an exposed second length, respectively, that are not covered by said filler material, where the exposed first length and the exposed second length are substantially equal.

14 (previously presented). The method of claim 1, further comprising providing said exposed ends of said first and second CNTs in said array with an exposed first length and an exposed second length, respectively, that are not covered by said filler material, where the exposed first length is greater than the exposed second length.

15-17 (canceled).

18 (original). The method of claim 1, further comprising providing for said transport of said thermal energy from said object with an associated thermal resistance of no more than about  $8 \text{ cm}^2\text{-K/Watt}$ .

19 (original). The method of claim 1, further comprising providing for said transport of said thermal energy from said object with an associated thermal resistance of no more than about  $0.1 \text{ cm}^2\text{-K/Watt}$ .

20 (previously presented). The apparatus of claim 7, wherein said exposed ends of said first and second CNTs in said array have an exposed first length and an exposed second length, respectively, that are not covered by said filler material, where the exposed first length and the exposed second length are substantially equal.

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21 (previously presented). The apparatus of claim 7, wherein said exposed ends of said first and second CNTs in said array have an exposed first length and an exposed second length, respectively, that are not covered by said filler material, where the exposed first length is greater than the exposed second length.

22-24 (canceled).

25 (original). The apparatus of claim 7, wherein said transport of said thermal energy from said object occurs with an associated thermal resistance of no more than about  $8 \text{ cm}^2\text{-K/Watt}$ .

26 (original). The apparatus of claim 7, wherein said transport of said thermal energy from said object occurs with an associated thermal resistance of no more than about  $0.1 \text{ cm}^2\text{-K/Watt}$ .

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### Reply To Examiner's Remarks

Claims 1, 3-7, 9-14, 18-21 and 25-26, as amended, are presented for consideration.

The Examiner rejects claims 1-2, 5-8, 11-12 and 14-26 under 35 U.S.C. 103(a) as obvious, and therefore unpatentable, over the combined disclosures in U.S. Patent No. 6,891,724, issued to DeLorenzo et al (the "DeLorenzo patent") and U.S. No. 5,818,700, issued to Purinton (the "Purinton patent").

The Examiner rejects claims 4 and 10 under 35 U.S.C. 103(a) as obvious, and therefore unpatentable, over the combined disclosures in the DeLorenzo patent, the Purinton patent and U.S. No. 5,837,081, issued to Ting et al (the "Ting patent").

The Examiner rejects claims 3 and 9 under 35 U.S.C. 103(a) as obvious, and therefore unpatentable, over the combined disclosures in the DeLorenzo patent, the Purinton patent and U.S. Patent No. 6,504,292, issued to Choi et al (the "Choi patent").

The Examiner rejects claim 13 under 35 U.S.C. 103(a) as obvious, and therefore unpatentable, over the combined disclosures in the DeLorenzo patent, the Purinton patent and U.S. Patent No. 6,713,151, issued to Dean et al (the "Dean patent").

Claim 1, as amended, recites a method for providing for transport of thermal energy from an object. The method comprises:

providing an array of carbon nanotubes or carbon nanofibers, referred to herein as "CNTs," embedded in a selected surface of a selected substrate having high thermal conductivity, where at least first and second CNTs in the array are oriented substantially perpendicular to the selected surface;

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after provision of the at least first and second CNTs in the array, filling at least a portion of an interstitial space between at least two adjacent CNTs in the array with a selected filler material that has high thermal conductivity so that the filler material makes contact with the selected substrate surface at a first end of each of the at least first and second CNTs and a second end of each of the at least first and second CNTs is exposed and is not fully covered by the filler material; and

causing the exposed second ends of the at least first and second CNTs to make contact with a surface of an object for which transport of thermal energy is to be provided so that at least one of the exposed second ends of the CNTs bends or buckles, whereby thermal energy is removed from the object through the at least first and second CNTs and a portion of the removed thermal energy is distributed within the filler material.

The DeLorenzo patent discloses use of a thermal conduction layer using CNTs and a CVDD process to achieve a thermal conductivity value of 1000-6000 Watts/meter-°K in removing heat from an integrated circuit or similar device, Figures 4, 5 and 6 of the DeLorenzo patent indicate how a layer of nanotubes 40 provides an interface between a die 14, from which heat is to be removed, and a CVDD heat dispersion coating 32 that conducts heat received from an (upper) end of one or more CNTs. The upper ends of the CNTs 40 shown in Figures 4, 5 and 6 appear to fit snugly against the coating 32, and the CNTs are not accompanied by a contiguous filler material.

The Purinton patent, in Figure 4, discloses nanoscopic metal fibrils 26, having diameters of the order of 25 nm, dispersed within already-existing pores of a polymer film 27 to fill valleys (also designated as 27) within a pad 28. As indicated in Figure 5, nanoscopic fibrils 31 deform under pressure to fill otherwise-unfilled spaces between heat conducting pads, 32 and 33. As shown in Figure 6,

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the metal fibrils 43 are spaced apart, and extend from a lower end to an upper end of a polymer film 41 that also includes unfilled spaces 42, and the upper ends of the metal fibrils may be flush with, or extend above, the upper surface of the polymer film

The Examiner appears to argue that provision of metal fibrils, within pores in a polymer filler material, is equivalent to provision of CNTs, surrounded by an interstitial, thermally conducting filler material. This argument is incorrect. With reference to the time, 13 April 2004, at which the subject patent application was filed, where an array of CNTs is to be used, the CNTs must first be grown on a catalyzed, approximately flat substrate, after which the interstitial material is added as filler between the extant CNTs. A CNT could not be reliably grown within an already-existing pore having a large aspect ratio (e.g., 100  $\mu\text{m}$  height divided by 25 nm diameter = 4000). The resulting carbon nanostructure has relatively low thermal conductivity and electrical conductivity. The process disclosed in the Purinton patent turns the CNT procedure around by beginning with the pores in the polymer material, then adding thermally conductive material (metals, alloys, conductive polymers) within the pores. This reversal of procedure may work where the conductive material is merely to be deposited in the pores, although the process is likely to be very slow for high aspect ratio pores. However, this reversal of procedure would not work for catalyzed growth of CNTs within a high aspect ratio pore, given the knowledge of CNT growth in April 2004.

Method claim 1, as amended, recites: (i) provision of an array of CNTs embedded in a selected surface of a substrate; (ii) provision of an interstitial material with high thermal conductivity between adjacent CNTs in the array, after the CNT is grown, so that second ends of the CNTs are exposed above the interstitial material; and (iii) causing the second ends of at least two of the CNTs to make contact with an object from which thermal energy is to be removed, by



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bending or buckling of the exposed portions of the CNT ends, whereby thermal energy is removed from the object through the at least first and second CNTs and a portion of the removed thermal energy is distributed within the interstitial material, for improved thermal energy dissipation.

The combined disclosures of the DeLorenzo patent and the Purinton patent do not teach or make obvious a combination of (i) growth of aligned CNTs on a selected substrate surface and (ii) provision of a high thermal conductivity interstitial material, between adjacent and already-existing CNTs, that receives and distributes, and thereby dissipates, a portion of the thermal energy from the object, through the CNT contacts with the object, using exposed ends of the CNTs above the interstitial material. The combined disclosures of the DeLorenzo patent and the Purinton patent also do not teach a method that could provide transport of thermal energy from the object with an associated thermal resistance of no more than about  $0.1 \text{ cm}^2\text{-K/Watt}$ , a very low value, as recited in claim 19, which depends upon amended claim 1. For these reasons, the Applicants believe amended claim 1, claim 19, and claims 3-6, 13-14 and 18 dependent thereon, are allowable over, and not obvious in view of, the combined disclosures of the DeLorenzo patent and the Purinton patent.

The Ting patent discloses provision of a catalyst, such as iron particles, associated with a substrate to promote growth of a carbon-carbon composite, beginning with a mat of interwoven carbon fibers with diameters  $\approx 1 \mu\text{m}$  (Figure 1), using a chemical vapor infiltration (CVI) process. A high temperature process ( $T \approx 2800 \text{ oC}$ ) is required to graphitize the carbon fibers, followed by a pyrolytic process to densify the graphitized carbon fibers (not required in the relatively low temperature process used in the subject invention).

The Dean patent discloses use of electroflocked, mechanically flocked, pneumatically flocked or similarly processed thermally conductive fibers,

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embedded at one fiber end in a substrate, to provide a fibrous thermal interface. The flocking appears to serve as an adhesive, to provide material with low thermal conductivity. The non-embedded end of one or more of the fibers (having diameters of the order of 3-100  $\mu\text{m}$ ) extends above the adhesive, and an encapsulant (e.g., a gel) is introduced to fill space between the fibers.

The Choi patent discloses a field emission device using nanostructures (e.g., carbon nanotubes), preferably vertically aligned, with high aspect ratios (e.g.,  $\approx 1000:1$ ). A thin metal film, having a thickness no more than about 100 nm, is coated on a substrate surface. The encapsulated nanostructure in the Choi patent is separated from, rather than being embedded in, a continuous matrix as recited in amended claim 1. The Choi patent appears to focus on electrical conductivity, rather than on thermal conductivity.

The combined disclosures of the DeLorenzo patent, the Purinton patent, the Ting patent, the Dean patent and the Choi patent also do not teach or make obvious a combination of (i) growth of aligned CNTs on a selected substrate surface and (ii) provision of a high thermal conductivity interstitial material, between adjacent and already-grown CNTs, that receives and distributes and thereby dissipates a portion of the thermal energy from the object, through the CNT contacts with the object, using extension of ends of the CNTs above the interstitial material.

Independent apparatus claim 7, as amended, corresponds to and contains the same limitations as amended method claim 1 and is believed to be allowable for the same reasons that amended claim 1 is allowable. Apparatus claim 26 depends upon amended claim 7 and corresponds to method claim 19. Claims 9-12, 20-21 and 25 depend upon amended claim 7 and are believed to be allowable if claim 7 is allowable.

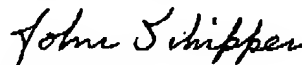
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The Applicants request that the Examiner pass the application, including claims 1, 3-7, 9-14, 18-21 and 25-26, as amended, to issue as a U.S. patent.

Respectfully Submitted,



John Schipper

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Patent representative for Applicants